# METHOD FOR CHECKING A BORE HOLE

The present invention relates to a method for checking a bore hole according to the definition of the species of Claim 1.

Pulsed laser drilling is used to produce bore holes having small diameters, for instance in hollow workpieces. Turbine blades, in particular, have a multitude of fine cooling air bore holes, which this method is able to produce with high positional accuracy and in an automated manner.

However, in order to achieve the cooling air flow rate required during operation these bore holes have to conform to exact tolerances with regard to their diameter. For that reason the dimensional accuracy of the produced bore holes must be checked.

Furthermore, it has to be ensured, for one, that the bore hole is complete, i.e., that it is not just a blind hole that is produced, and, for another, that the laser pulses are not continued once a bore hole has been completed and possibly damage the wall regions lying behind it.

For this reason, various methods for automated piercing and diameter detection have already been proposed, which infer the piercing instant and bore-hole diameter in a variety of ways on the basis of changes in specific features of the process radiation during pulsed laser drilling, cf. DE 38 35 980 A1 and DE 38 35 980 A1. However, experience has shown that drilling errors still occur even when using such checking methods, which cannot be tolerated given the high quality standards prevailing in the aerospace field, in particular.

Therefore, it is the object of the present invention to provide a checking method which detects drilling faults in a more reliable manner.

This objective is achieved by a method having the features of the generic part of Claim 1, by its characterizing features. Advantageous embodiments are indicated in the dependent claims.

According to the present invention, to check a bore hole that is introduced in a workpiece by laser pulses, characteristic signals from the area of the bore hole are received with the aid of a sensor and compared to setpoint values and only signals that are received in a characteristic time interval following a laser pulse are taken into account.

In contrast to methods from the related art, which check the process radiation during the duration of a laser pulse, the checking according to the present invention is implemented exclusively on the basis of signals received following a laser pulse. This detects drilling faults in a much more reliable manner since parts of the workpiece material are still present in the molten phase during and also even shortly after the process radiation has expired. Different physical phenomena, in particular minimizing the boundary surface energy, may cause the molten phase to find its way into the bore hole, where it solidifies and results in a partial or complete occlusion of the bore hole. High-speed recordings by a video camera provide proof of the occurrence of such drilling faults.

Drilling faults of this type cannot be detected by methods which examine the process radiation, but are able to be discovered by the method according to the present invention

since it begins the check only after these physical phenomena have run their course.

The comparison of the received signals with the setpoint values may be carried out according to the known methods, for instance according to DE 38 35 980 A1 or DE 38 35 980 A1.

In an advantageous embodiment, the characteristic time interval is thus defined as a function of material properties of the workpiece and process parameters of the laser pulse. Different instants for the beginning and the end of the time interval are conceivable: The absolutely earliest meaningful instant for the beginning is the instant at which at least a thin skin of the bore hole wall has solidified again; preferred is the solidification of the entire molten material; it is also possible to wait out a short interval thereafter. The earliest instant for the end of the time interval is given by the minimum length of the time interval required to receive a sufficient quantity of signal data. The latest instant for the end is the beginning of a subsequent laser pulse.

The individual instants may be ascertained empirically or by simulations according to known methods.

In an advantageous refinement of the present invention, signals of an optical and/or thermal type are received, which are emitted or reflected from the region of the bore hole. The advantage of this development is that it is especially easy to infer drilling faults on the basis of such data with the aid of known methods. However, acoustic signals are conceivable as well since the acoustic properties of an ideally circular bore hole differ significantly from those of a faulty drill hole.

The use of a CCD camera for the reception of the signals is particularly advantageous. Such cameras are available for the optical and thermal (IR) range and, with minimal manipulation, provide a much larger data quantity than optical or thermal point sensors. However, other electronic cameras such as a CMOS camera are suitable as well.

In another advantageous embodiment of the present invention, from the beginning of the time interval, a measuring signal of an optical and/or thermal type is emitted in the direction of the region of the bore hole. In this way, one is no longer limited to the reception of signals that still result from the energy input by the previous laser pulse, i.e., optical and/or thermal radiation of the already solidified, but presently still glowing, then still hot to warm bore hole wall.

The measuring signal may be emitted by the drilling laser or some other emitter. Decisive is that the energy input in the bore remains low enough so that the wall material of the bore hole will not melt again.

The method according to the present invention is particularly advantageous for checking the piercing of the workpiece wall and/or for deviations from a predefined drilling geometry, in particular in the case of turbine blades since the quality standards there are especially high and cannot be fully met by methods of the related art.

In the following text the method according to the present invention is elucidated in greater detail on the basis of two exemplary embodiments.

In a first exemplary embodiment, a characteristic time interval that is suitable for a given workpiece and specific laser parameters is first determined empirically. To this

end, some workpiece material is first melted and then observed during the transition from the molten to the solid phase, using an IR-CCD camera, in order to ascertain characteristic IR signals for the phase transition. Subsequently, continuous monitoring of a laser bore hole takes place with the aid of this IR-CCD camera. At a time when a relative equilibrium has already come about between energy input by the laser pulses and energy removal by heat transfer via bore hole wall and air, the time characteristic of the bore hole cooling is monitored, starting directly after the end of a laser pulse. This monitoring is repeated several times and the individual instant determined at which the characteristic signal of the phase transition is achieved at significant points of the bore hole. These times are averaged. The average value provides a reliable measure for the beginning of the characteristic time interval for the entire duration of the laser drilling since it is assumed that the cooling at the beginning of the drilling, i.e., before the relative equilibrium is reached, occurs faster due to the still cold bore hole environment. Selected as the end of the characteristic time interval is the beginning of the new laser pulse. Thus, one empirically obtains a defined time interval that begins at an instant a following the end of a preceding laser pulse, and that ends at an instant b at the beginning of a subsequent laser pulse.

Once a suitable characteristic time interval has been defined in this manner, the actual production monitoring of a turbine blade may take place. To this end, during the production process of each bore hole, the IR signals of the IR-CCD camera received during the characteristic time interval following each laser pulse are compared to previously defined setpoint values. The comparison is implemented according to methods known from the related art, for instance according to DE 38 35 980 A1 or DE 38 35 980 A1.

In this first exemplary embodiment, a complete IR image of the bore hole is recorded continuously with the aid of the IR radiation emitted from the region of the bore hole and received by the IR-CCD camera, and used to determine the piercing of the workpiece wall and deviations from a predefined bore hole geometry.

According to a second exemplary embodiment, at the beginning of the characteristic time interval an optical measuring signal is emitted in the direction of the bore hole region, where it is absorbed and re-emitted in the form of IR radiation. This additional measuring signal increases the measuring accuracy. However, care must be taken that the additionally input energy does not cause renewed melting of the bore hole wall and thereby damages the bore hole. The optical measuring signal can be generated in a simple manner with the aid of the drilling laser (by shortening the pulse duration and or intensity), but also by other emitters such as a stroboscope or by continuous illumination regularly interrupted by a chopper. Essential in this context is the synchronization of laser drill pulses and measuring signals, whose uniform interval must be ensured in order to exclude drilling errors due to uneven heating.

The method according to the present invention in the specific embodiments of the previously described examples has shown to be especially suitable for the rapid and simple checking of laser bore holes in turbine blades, since particularly high quality standards are required there, which are not able to be fully met by the related art.

The present invention is not restricted to the previously described exemplary embodiments only, but is transferable to additional embodiments as well.

For instance, the use of the method not only allows monitoring of the piercing and/or the bore hole geometry, but also the instantaneous bore hole depth, for example.

Furthermore, for a number of applications with slightly lower quality standards, measurements using optical/thermal/acoustic point sensors instead of a CCD camera or CMOS camera are sufficient as well.